N66 34435

# ORBITING SATELLITE SURFACE TEMPERATURE PREDICTION AND ANALYSIS

## I. Introduction

Temperature prediction of spacecraft orbiting the moon, earth or other planets is an essential Manned Spacecraft Center capability. Existing methods it was found, however, were either too simplified or specialized for MSC requirements. A contract was, therefore, let with Midwest Research Institute in Kansas City, Missouri, to develop a computer program to determine spacecraft heat loads and/or thin skin transient temperatures ~~while orbiting the~~ moon, earth or other planets. It is this computer program, which has recently been completed, that I'd like to introduce. The computer program is written for the IBM 7094 computer and is in the Fortran II language.

## II. Spacecraft Thermal Balance

First to give some insight into what are some of the major considerations in determining the thermal balance of an orbiting spacecraft, figure 1 shows the principal external heat loads. The q sun represents solar thermal radiation coming from the sun and directly impinging upon the vehicle. The q albedo represents that quantity of solar radiation from the sun that is reflected off the planet being orbited and then impinging upon the orbiting vehicle. Lastly, the q planet is that thermal radiation from the planet orbited that impinges upon the vehicle.

When the vehicle is on the far dark side of the planet, however, it can be seen that the vehicle would not receive any q sun or q albedo; therefore another consideration is the sun-shade points.

## III. Major Features and Capabilities

Before proceeding further with the fundamentals of the program, however, I would like next to outline some of the major features and capabilities of the program. They are as follows:

1. The program has the capability of handling up to 200 elements; each has its own thickness, initial temperature, and thermal properties.

2. The program also has the capability to consider eight different coatings and eight different substrate materials. The thermal properties of each may be temperature dependent.

3. A spinning or fixed vehicle orientation may be considered. The fixed orientation may be with respect to the sun or the planet being orbited.

4. Internal heat may be considered as a function of time. The program has the capability to handle eight different internal heat tables.

5. Constant or variable planet temperatures may be considered. This feature is a most important consideration for a lunar orbital mission. The significance will be shown later for a hypothetical lunar mission.

IV. Assumptions

In order to meet the projects objectives, it was necessary to introduce certain simplifying assumptions. I feel that it is worthwhile at this time to introduce these assumptions for it is up to each individual user or potential user to evaluate the validity of the assumptions for each intended application.

1. Conduction between elements, and convection between the vehicle and its surroundings are neglected. When MSC feels conduction between elements could be a significant factor, the program is used only to compute the incident heat loads and then these outputs are loaded as input into a transient conduction type program.

2. No radiant interchange between elements is considered.

3. All thermal radiation is considered to be diffused.

4. The vehicle's absorptivity to reflected solar radiation is assumed to be equal to the vehicle's absorptivity to direct solar radiation.

5. Internal heat is assumed to be uniformly distributed over the element.

6. The solar constant is assumed to be independent of the vehicle's orbital position.

7. On the sunlit side of a variable temperature planet, the planet surface temperature is assumed to vary according to Lambert's cosine law. The planet temperature on the dark side of a variable temperature planet is, however, assumed constant.

## V. Celestial Mechanics

So far nothing has been said about input data. A general outline of the type input required shall therefore be presented next. It is believed that the input is quite simple and logical.

To compute the heat loads to an orbiting vehicle, four basic questions must be considered. They are:

1. What is the location of the vehicle surface element on the vehicle?

2. Where is the vehicle with respect to the planet being orbited?

3. What is the celestial location of the vehicle with respect to space?

4. What is the sun's location with respect to the planet being orbited?

### Vehicle Coordinate System

The first question is not applicable to a spinning satellite; however, for an oriented vehicle, the incident heat flux can vary considerably from one surface position to another. For example, looking at figure 2, the element on the side of the planet oriented vehicle shown in the upper left hand corner receives radiation from the planet whereas the element on top does not. Consequently, a system to answer the first question (What is the location of element analyzed?) is required for the thermal analysis of an oriented vehicle.

A meaningful vehicle coordinate system is set up by replacing the complex configuration with a spherical mathematical model shown in the upper right hand corner of figure 2. The elements on the sphere are selected so they have the same space orientation as the corresponding vehicle elements.

For a planet or moon oriented vehicle, the surface positions on the sphere are defined with respect to the coordinate system illustrated in the lower left hand corner of the figure. For the sun oriented case, the surface positions on the sphere are defined with respect to the coordinate system illustrated in the lower right hand corner. For a fixed orientation, the surface elements location is defined by the angles $\Lambda$ and [illegible] as shown and are required input data for each element. This system can be likened to defining a position on earth where any position on earth can similarly be defined by giving the proper longitude and latitude.

## Planet Coordinate System

Before the impinging heat loads emitted or reflected by the planet can be computed, the second question (Where is the vehicle with respect to the planet being orbited?) must be answered. The answer to this question can be obtained in terms of the planet coordinate system shown in figure 3, using Kepler's equations. The input required by the program to compute internally the vehicle's position with respect to the planet consist only of the semi-major axis (a), semi-minor axis (b) of the orbital ellipse and the true anomaly ($\phi$) at the initial time. The three variables are shown in the top right hand corner of the slide which shows the orbit rotated into the plane of the screen, and the $X_p$ and $Y_p$ axes superimposed onto the orbit plane. As shown for a spinning or fixed orientation, the planet coordinate system is the same.

## Celestial Coordinate System

The third question (What is the celestial location of the vehicle with respect to space?) involves defining the orbit with respect to space. This question can be answered in terms of the celestial coordinate system. The vehicle's orbit can be conventionally related to the celestial coordinate axes by three angles which are required input data. These angles are shown in figure 4 where $\Omega$ is the right ascension of the ascending node, $\omega$ is the argument of perifocus, and $i$ is the inclination of the orbital plane.

Any reference system could have been selected for the celestial coordinate system; however, the basis of selection was that it be compatible with standard astronomical references to minimize input data compilation time and effort. With this as a criteria for selection of a celestial coordinate system three systems, geocentric, modified heliocentric and the selenographic were chosen to describe orbits about the earth, a planet other than earth, and the moon respectively.

For earth and planets other than earth, the two celestial coordinate systems used are pictured in figure 5.

For the moon the third celestial coordinate system selected is illustrated by figure 6.

## Sun's Position

The only question that remains now to be answered is: What is the location of the sun with respect to the planet being orbited? This can be answered in terms of two angles, the right ascension of the sun (RA) and the declination (DEC). Both angles are required input data to the program and are defined by figure 7.

Since we were careful in our selection to choose a celestial coordinate system that would be compatible with standard astronomical references, we can obtain from the Ephemerus the RA and DEC for the moon, earth or any other planet for any particular date.

## VI. Hypothetical Test Case

### Case I

A hypothetical lunar mission was run using the described program. For this particular lunar orbital mission, the spacecraft was planet oriented and the variable planet surface temperature feature of the program was used. The mission data was selected in order that the sun would be very near to being in the orbital plane.

Pertinent orbit data consisted of the following:

Altitude 10 NM to 190 NM.

Inclination = $13^\circ$.

Right ascension of ascending node = $.87^\circ$.

Argument of perifucus $270^\circ$.

True anomaly at initial time = $0^\circ$.

The temperature time history of differently oriented and painted surface elements reveal several interesting characteristics.

The results shown in figure 8, a white element cools initially even though it is almost facing directly into the sun. A similarly oriented black element shown in the same slide, however, rises to a peak at = $60^\circ$, then gradually drops as it turns away from the sun. This is true since the white element reflects a considerable amount of solar energy, whereas the black energy will absorb the majority of solar radiation that impinges upon its surface.

In the next figure (9) the temperature curves of a black and white element facing the moon are very similar since black and white elements absorb long wavelength radiation almost equally. Also of interest shown in the figure is the hump in the black element's curve at about = $100^\circ$ and = $260^\circ$. This is caused by the fact that both elements are briefly irradiated by the sun just before entering the moon's shadow and just after leaving its shadow. However, the hump shows up only in the black element's curve since it absorbs the solar radiation more readily.

Comparison of both black elements in figure 10 reveals at = $0^\circ$ the element facing the moon is almost as hot as the element facing away from the moon and almost looking directly at the sun. This demonstrates that at low lunar orbits, the planet heat can be as significant as solar heat.

Case II

Finally, to learn the effects of not considering the moon's surface temperature gradient, a similar run was made of Case I; however, this time the moon was taken as a constant temperature planet. The results shown in the final figure (11) reveal the "constant moon temperature" curve $\Delta$ is a flat curve that averages out the maximum and minimum peaks of the "variable moon temperature" curve O. As you can see, we have a significant variation (about $100^{o}R$) caused by neglecting the moon's surface temperature gradient. These results confirm the importance of the variable planet temperature method in analyzing lunar missions.

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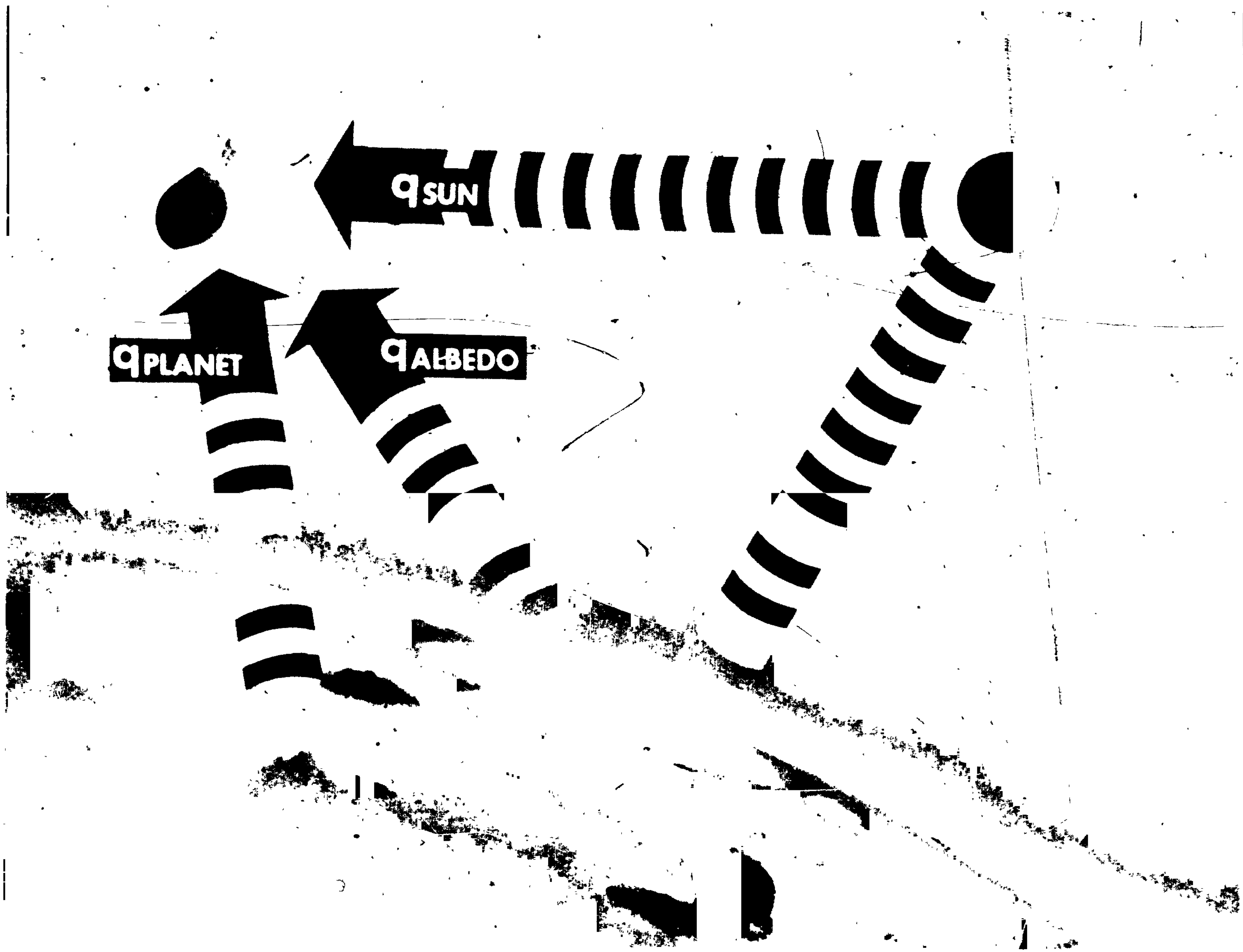



1 Principal External Heat Loads

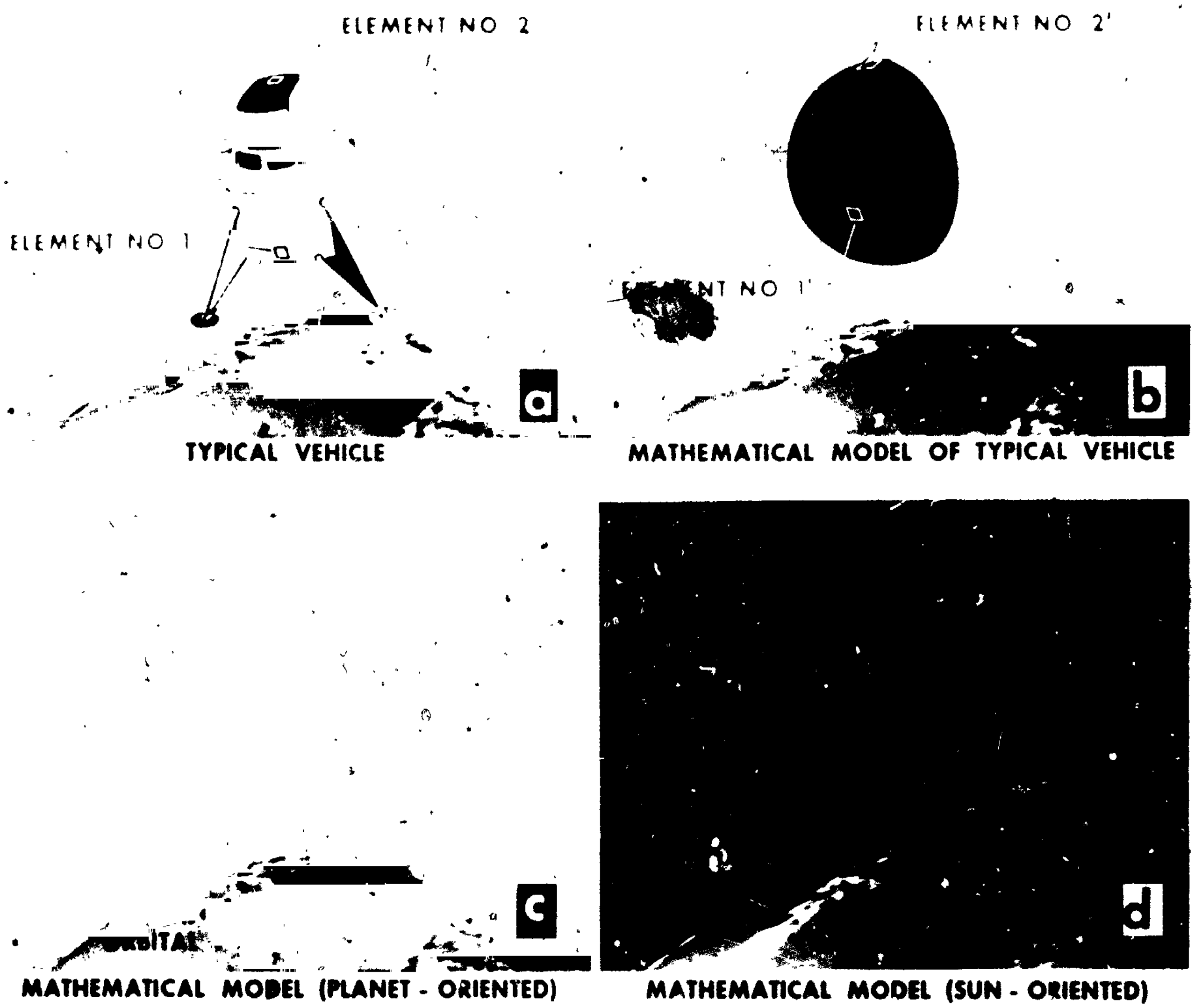



Fig. 2 - Vehicle Coordinate System for a Typical Spacecraft

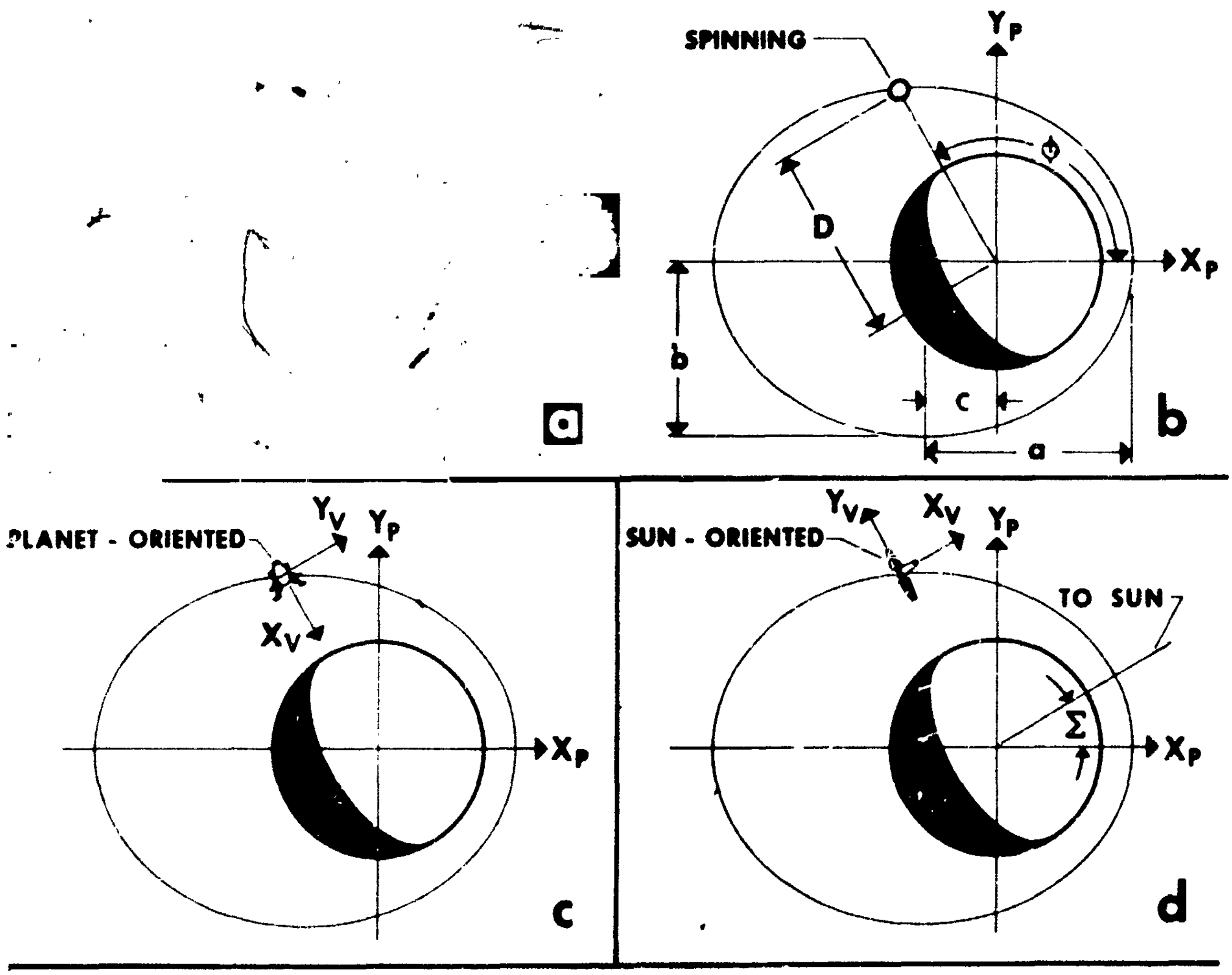



Fig. 3 - Planet Coordinate Systems for Spinning and Oriented Vehicles

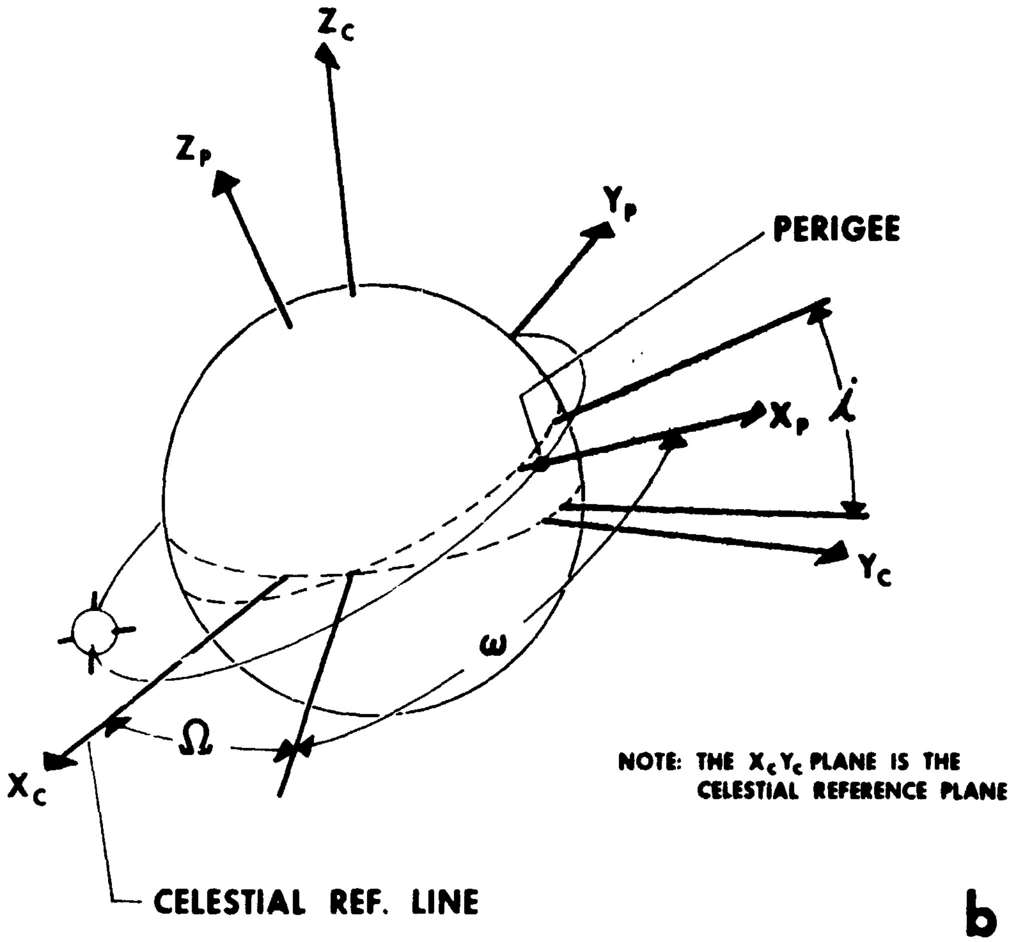
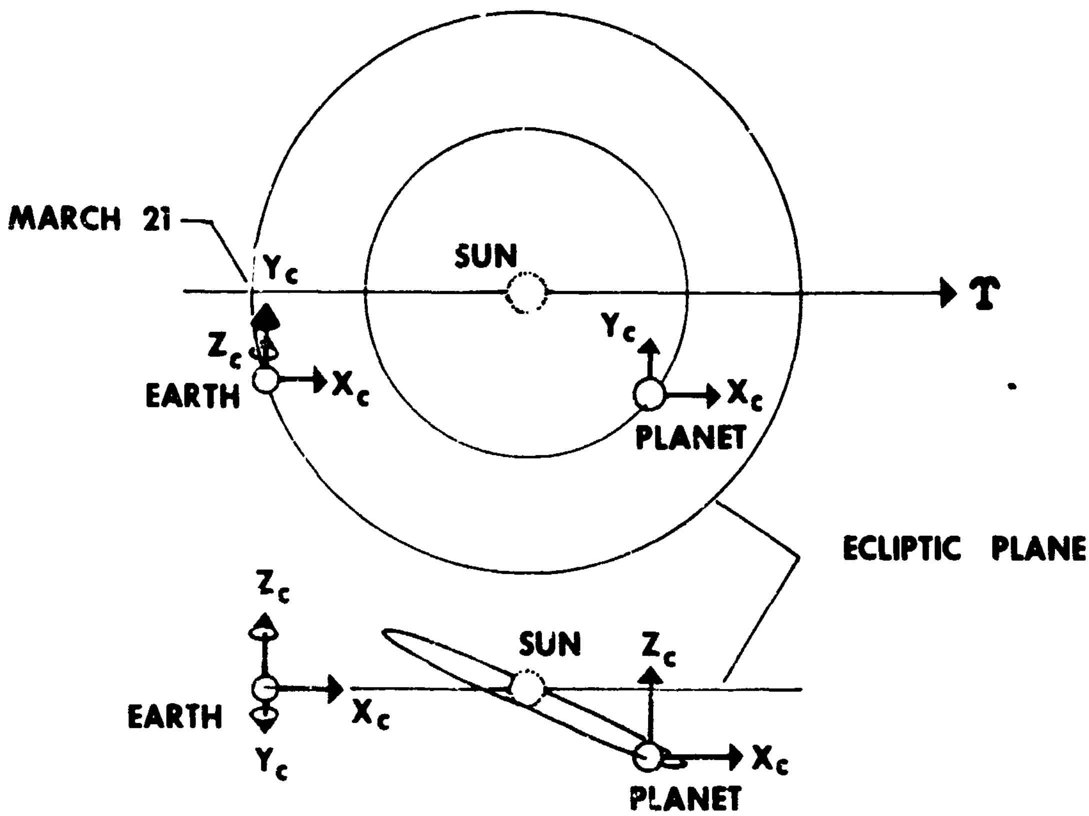



Fig. 4 - Relationship between Orbit and General Celestial Coordinate System




**NOTE: EARTH'S $X_cY_c$ AXES LIE IN ITS EQUATORIAL PLANE**
**PLANET'S $X_cY_c$ AXES ARE PARALLEL TO THE ECLIPTIC PLANE**

Fig. 5 - Celestial Coordinate System for Earth (Geocentric) and Other Planets (Modified Heliocentric)

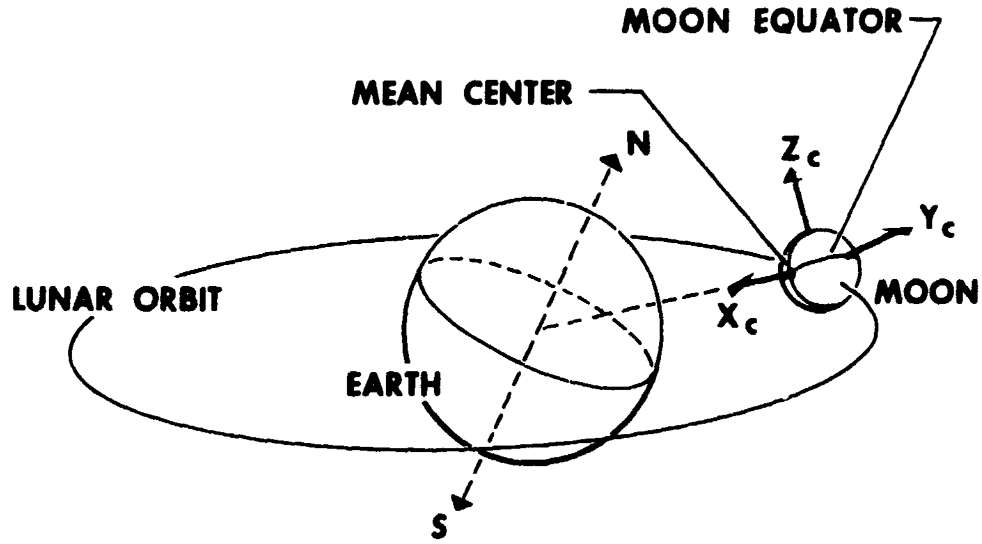



Fig. 6 - Celestial Coordinate System for the Moon (Selenographic)

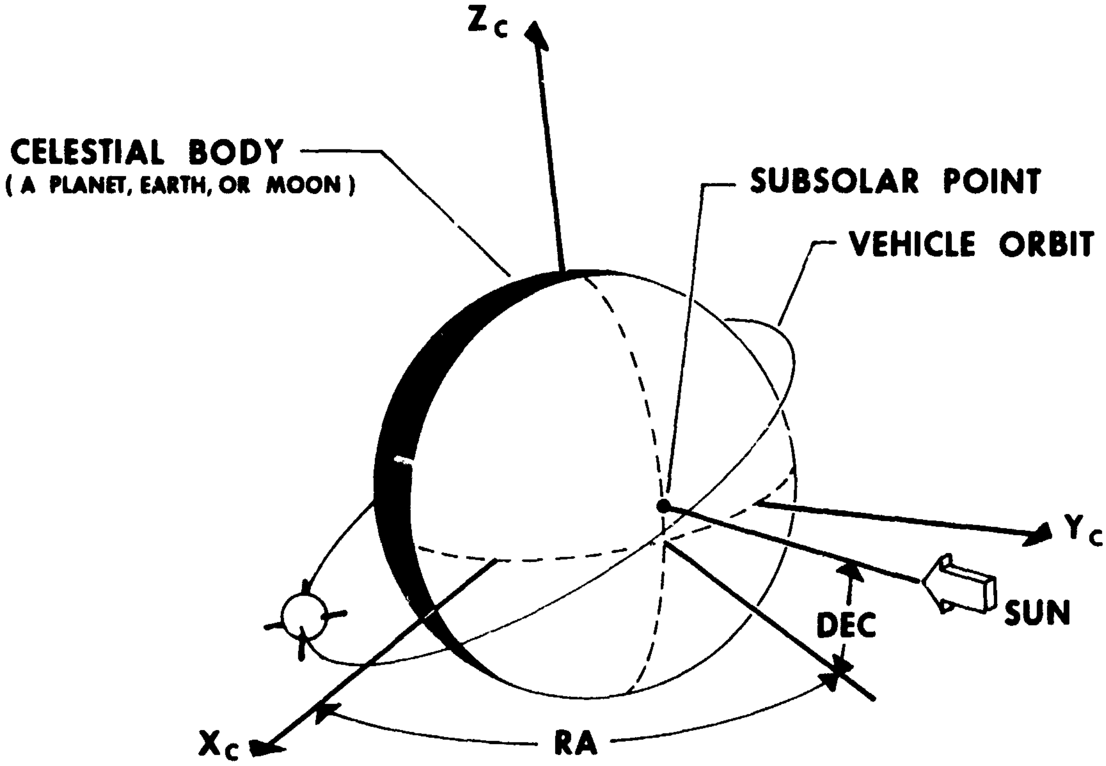
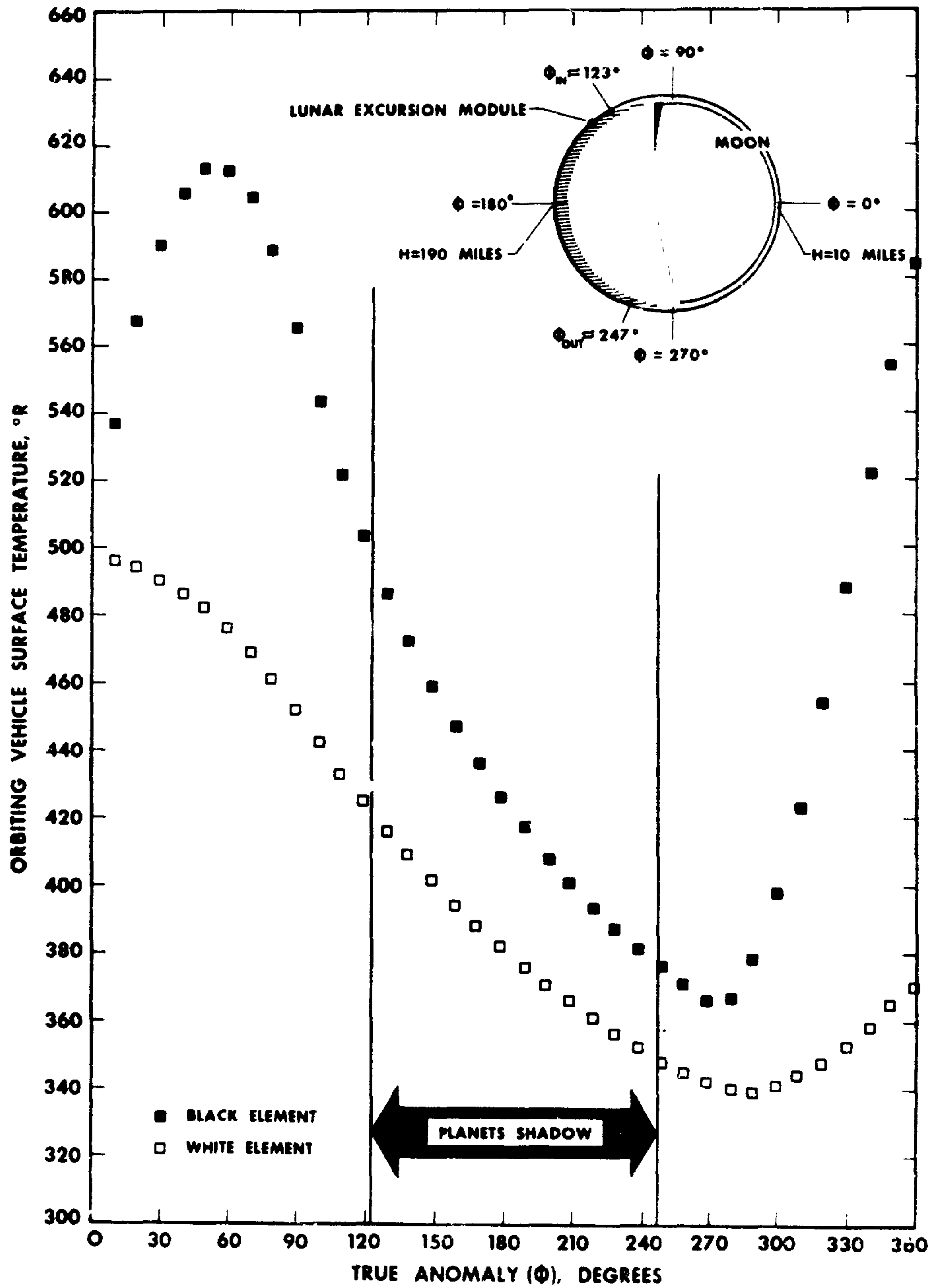



Fig. 7 - Sun's Position Relative to the Celestial Coordinate System

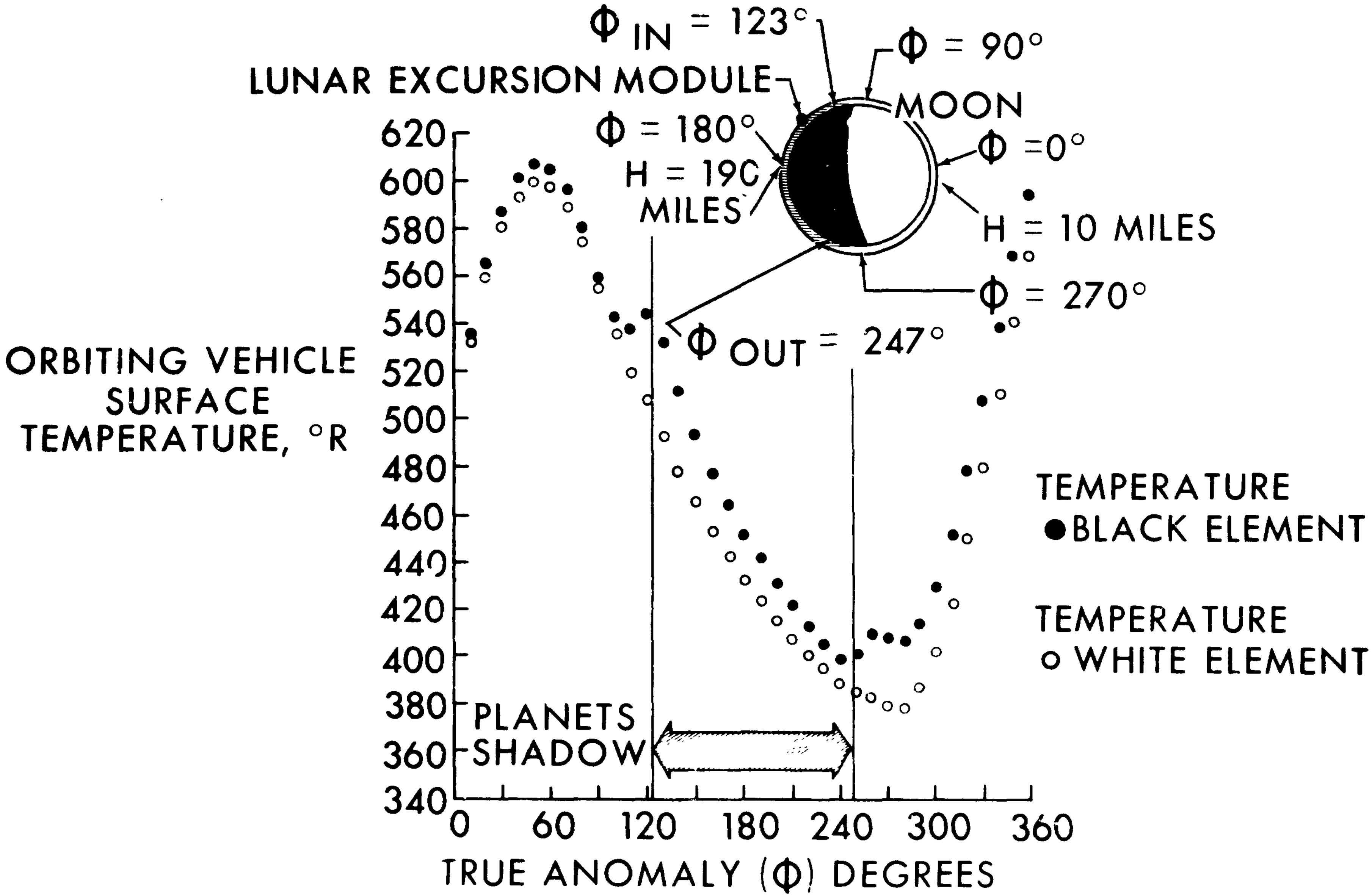



Simulated Lunar Excursion Module; Elements Face Away from the Moon

NASA-S-64-3199

# SIMULATED LUNAR EXCURSION MODULE

ELEMENTS FACE THE MOON



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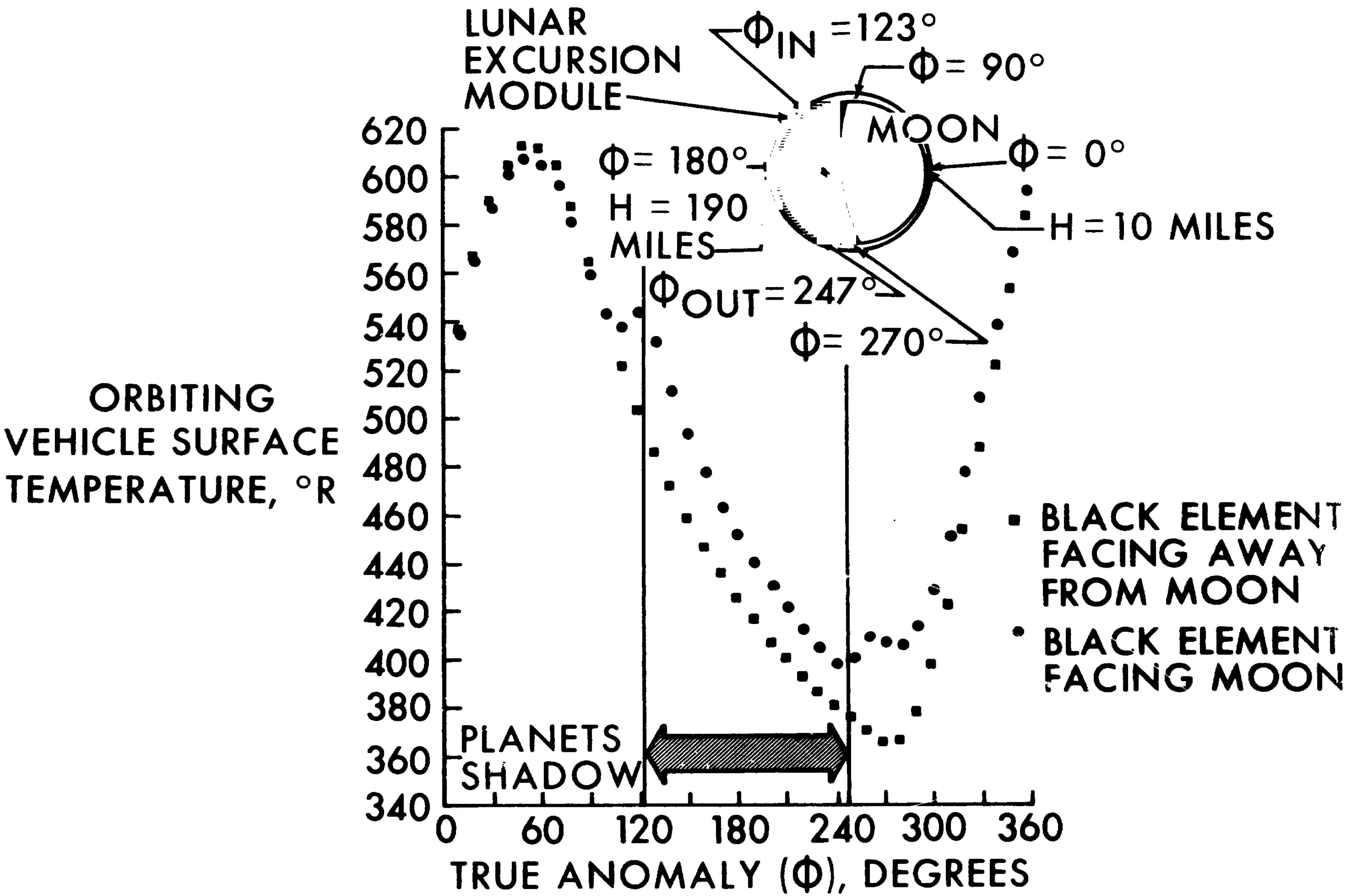

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# SIMULATED LUNAR EXCURSION MODULE

## ELEMENTS FACE THE MOON